Supplementary Shielding Calculation
for the GNS 11 Transport Cask

GNS

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# 0. Summary

In the GNS Report GNS B 38/86 /1/, criticality calculations were conducted for the GNS 11 transport cask with regard to different MTR fuel assemblies from research reactors with various variations of basket.

Among other things, the basket for 33 square-shaped MTR fuel assemblies was examined. The reference fuel assemblies used were of the types FRJ 1 (22 fuel plates), and FRM, BER and FRG (23 fuel plates in each case) with a U-235 content of 270 g per F/A at a maximum enrichment of 94 % (HEU F/A).

$k_{eff}$ values of < 0.90, and hence adequate criticality safety, were obtained for both types of fuel assembly.

Supplementary criticality calculations were conducted for this report with a view to the imminent or future transport of a maximum of 33 square-shaped MTR fuel assemblies with different fissile material - and total uranium masses with different types of enrichment (HEU, MEU, LEU). The reference fuel assembly used was the fuel assembly with 23 fuel plates, which is also used in the same form in other research reactors (e.g. GKSS, FZS, PSI etc.)

In the calculations the maximum expected fissile material masses (most reactive case) were allocated to each of the HEU, MEU and LEU fuel assemblies.

Three calculations were conducted with the following parameters:

| F/A Data | Type of Enrichment for Reference F/A HEU | MEU | LEU |
|---|---|---|---|
| Mass U-235 (nominal) | 280 g ± 1.5 % | 322 g ± 1.5 % | 400 g ± 1.5 % |
| Mass U-235 (maximum) | 284.2 g | 326.8 g | 406 g |
| Enrichment | 93 % | 45 % | 20 % |
| U total (nominal) | 302 g 1.5 % | 715.5 g ± 1.5 % | 2000 g ± 1.5 % |
| U total | 305.6 g | 726.2 g | 2030 g |

The results of these calculations were as follows for 33 fuel assemblies in the cask in each case:

- HEU F/A: $k_{eff} = 0.0870 \pm 0.004$ ($1\sigma$),
- HEU F/A: $k_{eff} = 0.9094 \pm 0.005$ ($1\sigma$),
- LEU F/A: $k_{eff} = 0.9293 \pm 0.004$ ($1\sigma$),

i.e. there was adequate criticality safety in each case.

With these results it can be seen that adequate criticality safety will be present for F/A loads with fissile material contents or enrichment below the above levels.

This also applies when the baskets are only partly loaded (e.g. 28 F/A in a 33 basket) and when there are mixed loads in the basket, containing HEU, MEU and LEU fuel assemblies, taking due account of the maximum U-235 masses listed above.

# 1. Introduction and Tasks

The aim of the following investigation is to verify the criticality safety of the GNS11 cask. The cask is designed for the dry transport of spent MTR fuel assemblies.

Supplementary calculations to those already conducted for GNS B 38/86 /1/ were conducted for fuel assemblies form other research reactors (e.g. GKSS, FZS and PSI), specifically with a view to imminent or future transport operations.

Fuel assemblies of the same design were used with different fissile material and total uranium masses and with different types of enrichment (HEU, MEU and LEU fuel assemblies).

The load in the GNS 11 was strictly limited to the already used basket for 33 square-shaped MTR fuel assemblies (see Fig. 2).

For the criticality safety analysis, only the flooded cask state was considered (with unborated water) such as may pertain when the casks are loaded or unloaded. A criticality analysis of the dry state is unnecessary since the MTR fuel assemblies are always subcritical, owing to the small quantity of fissile material in the dry state. The criticality calculations were always based on an unlimited number of casks.

The GNS 11 cask has a cylindrical cross section. The body of the cask consists of a sandwich configuration made of stainless steel/lead/stainless steel. The cavity cross section is 72.3 cm. The height of the cavity is 94.1 cm. The cask lid and the fuel basket are made of stainless steel.

In the criticality calculations, fresh, undepleted fuel assemblies were always assumed, ignoring any burn-up poisons.

## 2. Computational Method

The criticality calculations were performed with the aid of the SCALE program system /2/. For criticality calculations, this program contains various cross-sectional libraries, from which the 16 group Hansen-Roach library was selected here (with 5 thermal groups $\leq$ 3 cV). The program system possesses further routines for treating self-shielding according to Bondarenko's method /3/ or according to Nordheim's method /4/ for these cross sections. Each of the programs is called up according to the given resonance data.

Furthermore, the XSDRNPM code /5/ is integrated into the program system, and with this the cell-weighted cross sections can be generated. The self-shielded or cell-weighted cross sections are then fed into the KENO Va program /6/ to calculate the multiplication factor. The program system also possesses several auxiliary programs, e.g. to calculate the Dancoff factor of nuclide number densities or for the automated transfer of the cross sections.

The fuel assemblies were represented in the calculation by cell-weighted cross sections. The neutron statistics for determining the multiplication factor $k_{eff}$ with the KENO Va program is based on 100 iterations of 300 neutrons each, although the first three iterations are not counted.

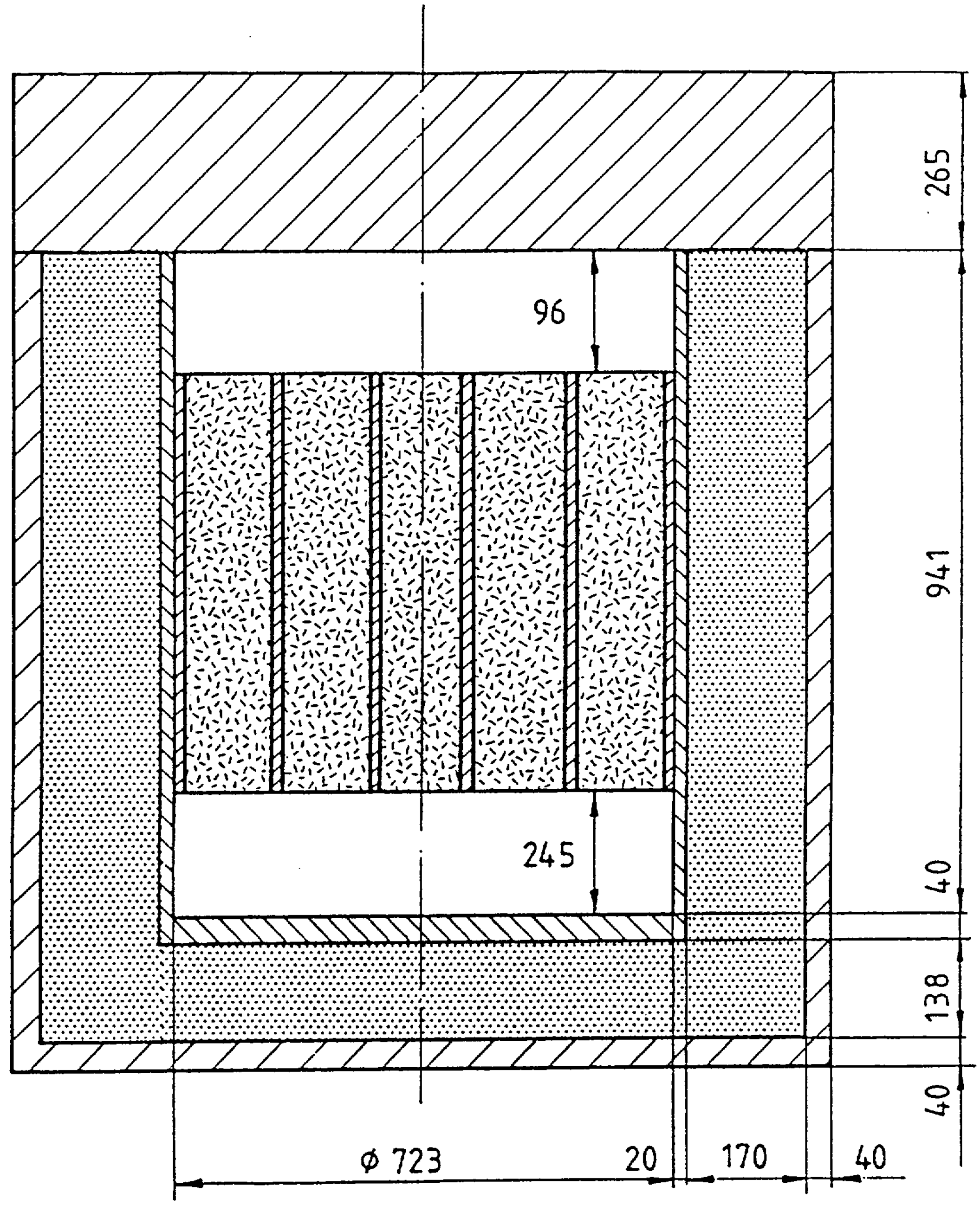
## 3. Computer Model

The computer model for the cask is sketched in Fig. 1. The cross section of the basket for 33 square-shaped MTR fuel assemblies is shown in Fig. 2. The computer model for the MTR reference fuel assembly can be seen in Fig. 3.

The radial structure of the various fuel baskets was modelled exactly in the computer model. Only those portions of the basket material and the F/A structures located in the region of the active fuel zone were taken into account. That is, only the steel portion of the basket above a height of 60 cm was considered in the calculations. The fuel assemblies were also only reproduced in the region of the active F/A zone, and the non-active upper and lower end pieces were replaced conservatively by moderating water.

The wall thickness of the cask in the side wall region consists of 4 cm stainless steel (outside), a 17 cm thick layer of lead in the middle and a 2 cm thick inner layer of stainless steel (1.4541 in each case). The bottom of the cask is similarly constructed; however, the thickness of the inner liner there is 4 cm, and the lead layer is 13.8 cm thick. The lid consists of 26.5 cm stainless steel (1.4313). On the outer side wall surface of the cask, mirror reflection of the neutrons was assumed. In this way, the multiplication factor calculated corresponds to an unlimited configuration of such casks.

In the calculation the reactivity-reducing effect of the 3.5 cm thick protection cap and the top and bottom impact limiters were ignored.




Alle Abmessungen in mm

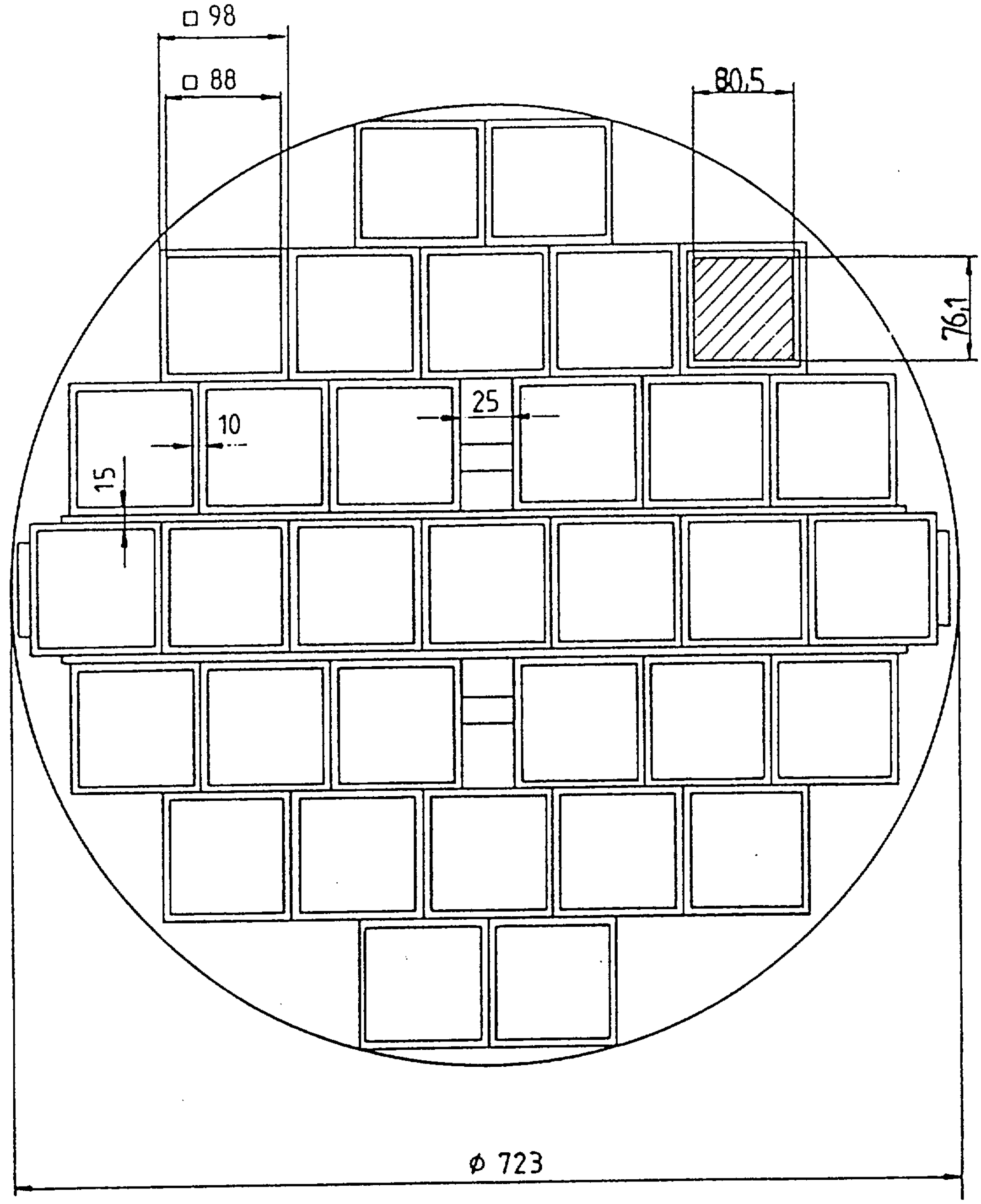
All dimensions in mm

Blei / Lead

Stahl / Steel

U Al$_x$+Al
bzw. $U_3O_8$+Al

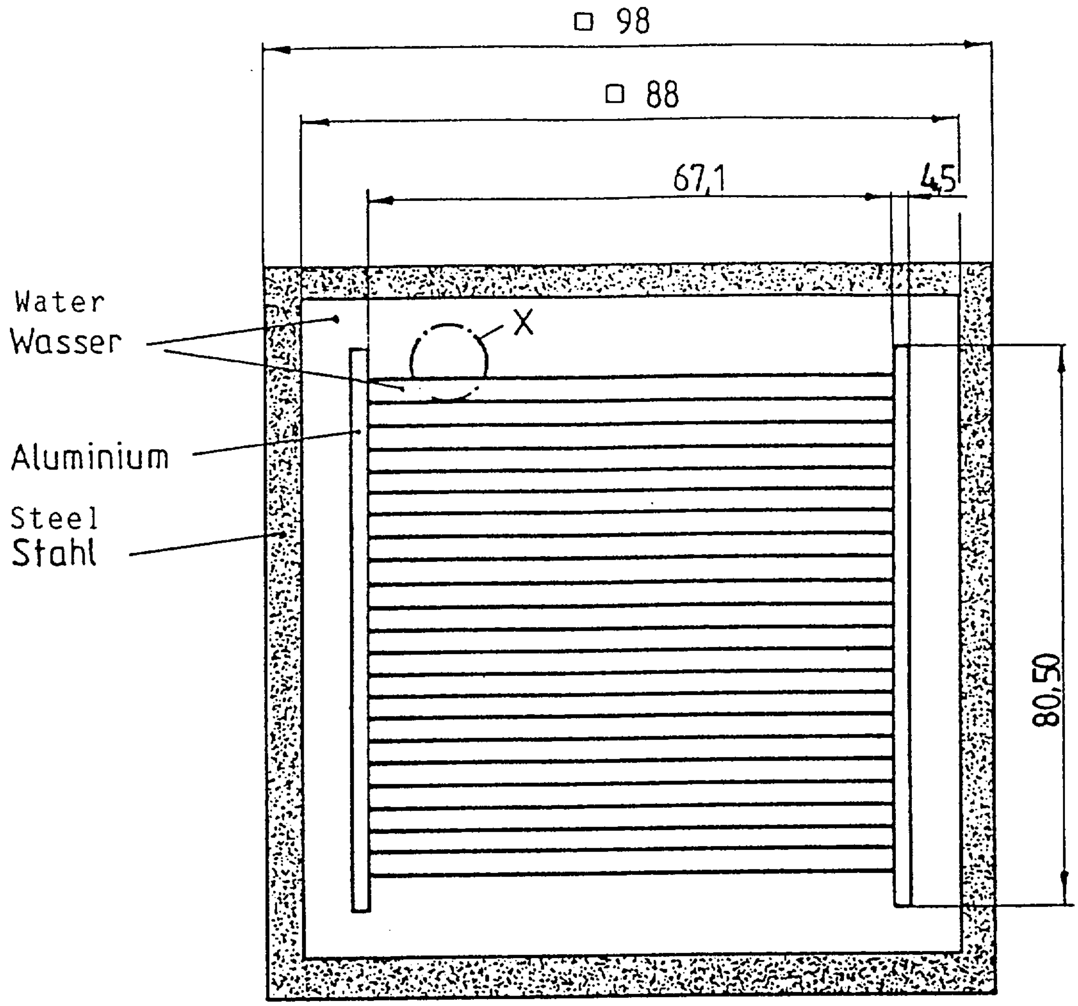
| | | |
|---|---|---|
| GNS | Geometry for Criticality Calculations | Fig. 1 |



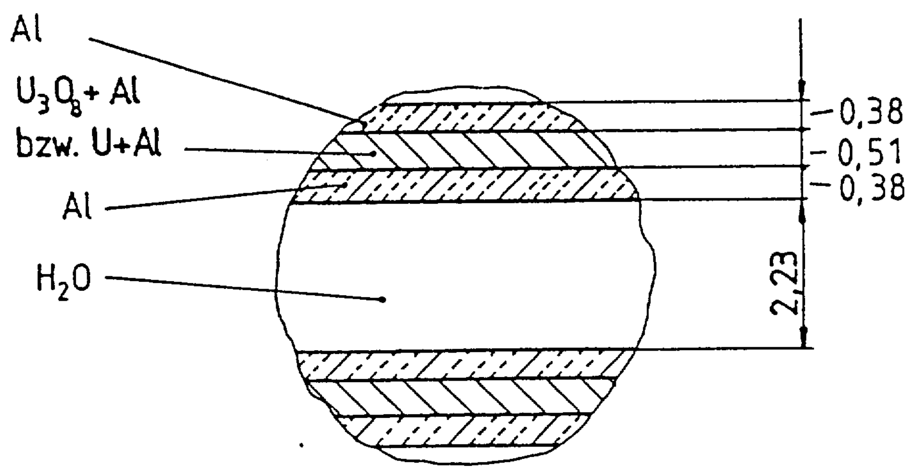

Alle Abmessungen in mm

All dimensions in mm

| | | |
|---|---|---|
| GNS | Basket for 33 Square-shaped MTR Fuel Assemblies | Fig. 2 |




All Dimensions in mm
Alle Abmessungen in mm




DETAIL "X"

| | | |
|---|---|---|
| GNS | Calculation Geometry for MTR Fuel Assemblies Type GKSS, OFZS, PSI | Fig. 3 |

# 4. Fuel Assembly and Structural Data

## 4.1 General Input Data for the Reference Fuel Assembly

| | | |
|---|---|---|
| F/A cross section: | (80.5 x 76.1) | $mm^2$ |
| Length of the active zone: | 600 | mm |
| Number of plates: | 23 | |
| Distance between plates: | 2.23 | mm |
| Total F/A length: | 873 | mm |

Plate structure:

| | | |
|---|---|---|
| - Total thickness | 1.27 | mm |
| - Cladding thickness | 0.38 | mm |
| - Fuel layer thickness | 0.51 | mm |

Densities:

| | | |
|---|---|---|
| - Uranium density (HEU and MEU F/A) | 19.05 | $g/cm^3$ |
| - $U_3O_8$ density (LEU F/A) | 8.30 | $g/cm^3$ |
| - Aluminium density | 2.699 | $g/cm^3$ |

## 4.2 Special Input Data for Different Types of Enrichment of the Reference Fuel Assembly

| F/A Data | Type of Enrichment for Reference F/A HEU | MEU | LEU |
|---|---|---|---|
| Mass U-235 (nominal) | 280 g ± 1.5 % | 322 g ± 1.5 % | 400 g ± 1.5 % |
| Mass U-235 (maximum) | 284.2 g | 326.8 g | 406 g |
| Enrichment | 93 % | 45 % | 20 % |
| U total (nominal) | 302 g 1.5 % | 715.5 g ± 1.5 % | 2000 g ± 1.5 % |
| U total | 305.6 g | 726.2 g | 2030 g |

## 4.3 Structural Data

| | |
|---|---|
| F/A structural parts: | Aluminium |
| Fuel: | Uranium-aluminium mixture /HEU, MEU F/A)<br>$U_3O_8$-aluminium mixture (LEU F/A) |
| Basket: | Stainless steel No. 1.4541<br>Density = 7.80 $g/cm^3$ |
| Cask: | Stainless steel/lead/stainless steel |
| | <u>Stainless steel</u>, No. 1.4541<br>Density = 7.80 $g/cm^3$ |
| | <u>Lead</u>, (DIN 1719, No. 2.3085)<br>Density = 11.0 $g/cm^3$ |
| Cask lid: | Stainless steel, No. 1.4313<br>Density = 7.80 $g/cm^3$ |

The calculations relate uniformly to a temperature of 293 K and a water density of = 1.0 $g \cdot cm^{-3}$.

## 5. Computational Results

The results of the criticality calculations are shown in Table 1 for the individual types of enrichment of the reference fuel assembly.

| Type of enrichment | $k_{eff} \pm 1\sigma$ |
|---|---|
| HEU F/A | $0.8870 \pm 0.004$ |
| MEU F/A | $0.9094 \pm 0.005$ |
| LEU F/A | $0.9293 \pm 0.004$ |

Table 1: Results of Criticality Calculations for the GNS 11 Transport Casks

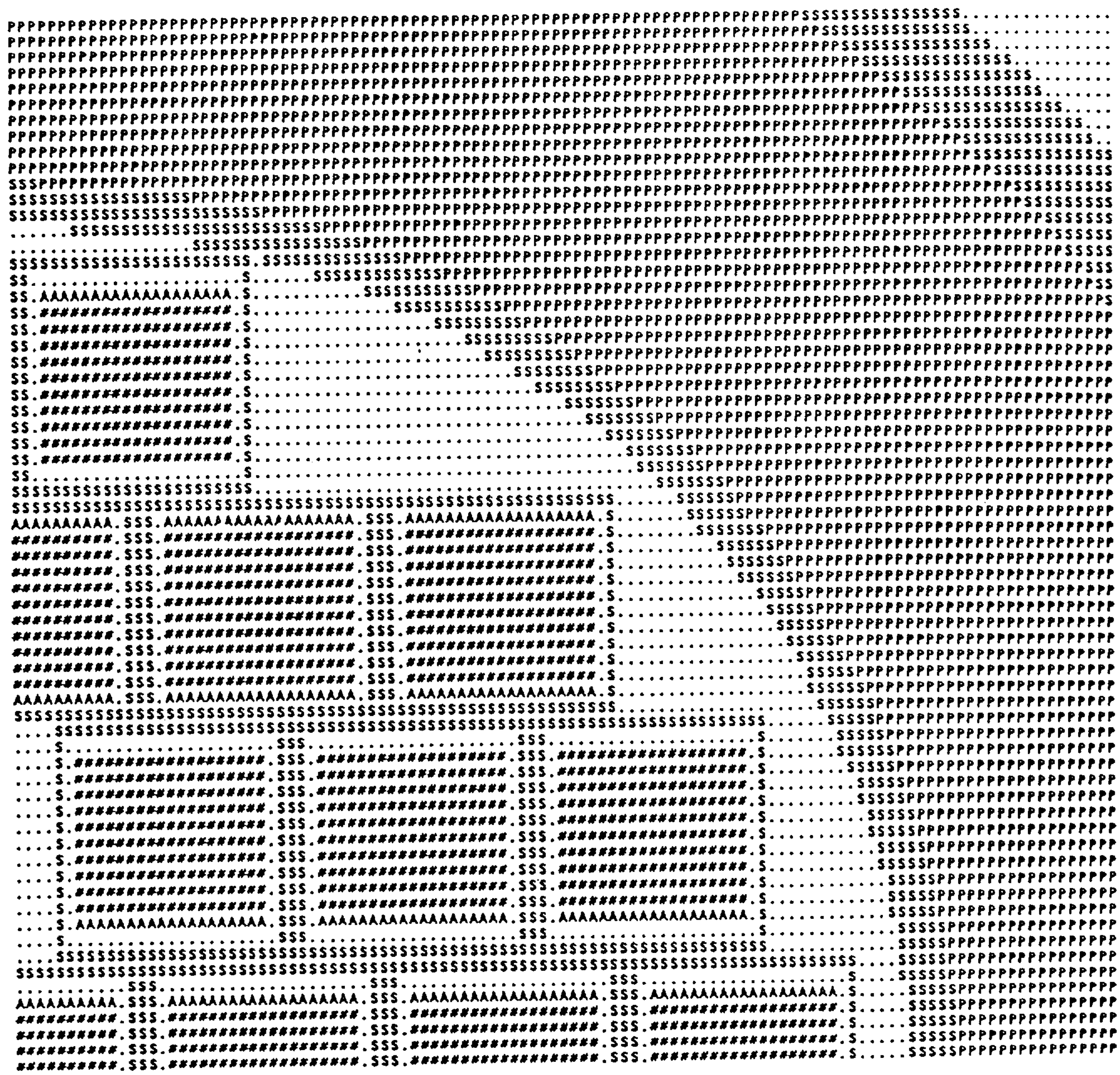
The maximum value in the double statistical scatter is, for the LEU fuel assembly, $k_{eff} + 2\sigma = 0.9373$ and is sufficiently below the design limit of 0.95. Thus, the usual mechanical tolerances, fluctuations in the material specifications or possible temperature effects are covered.

In this way mixed loads of, for example, HEU, MEU and LEU fuel assemblies in the 33 basket, as well as part loads (e.g. only 28 fuel assemblies in the basket), are also to be regarded as subcritical.

The same applies in a similar fashion to loads with fuel assemblies whose content of fissile material or degree of enrichment is smaller than assumed in section 4.2.

Fig. 4 shows the computer outprint of the quarter symmetry of the GNS 11 cask cross section loaded with 33 LEU fuel assemblies.

Fig. 5 highlights the statistical determination of the $k_{eff}$ during the KENO run for the GNS 11 with 33 LEU fuel assemblies.



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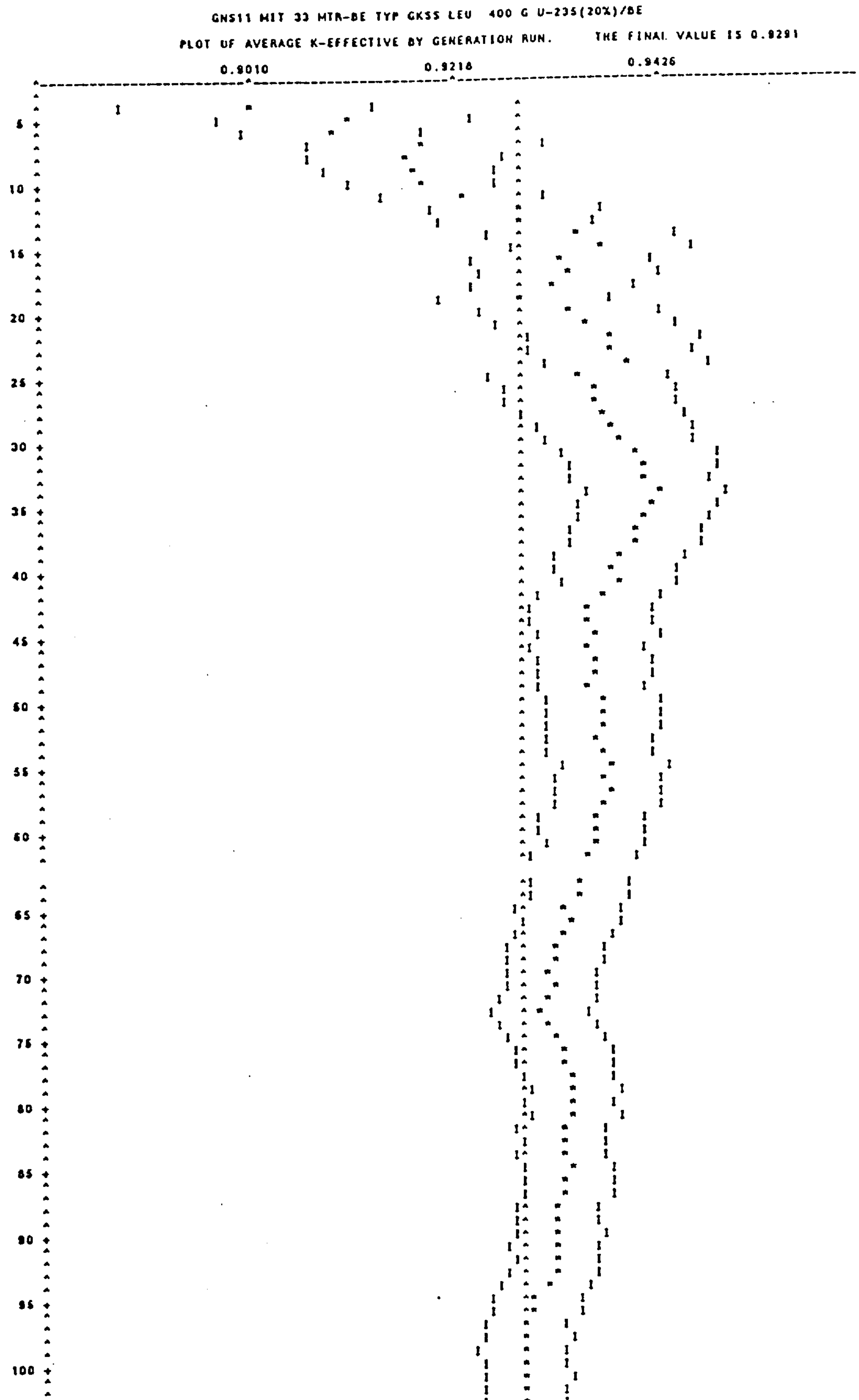
Computer Printout of Quarter
Symmetry of Cask Cross Section
GNS 11

Fig. 4




| GNS | Statistical Determination of the $k_{eff}$ during the KENO Run for the GNS 11 with 33 LEU Fuel Assemblies | Fig. 5 |
|---|---|---|

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